

Community Software Standards and Infrastructure for R2A

Cecelia DeLuca and Rocky Dunlap
NOAA ESRL/CIRES/University of Colorado

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Elements of R2A

Objects?

- Model components
- Datasets
- Metadata
- Scripts and workflows
- Diagnostics



- Model components
- Datasets
- Metadata
- Scripts and workflows
- Diagnostics

Actions?

- Goal-setting
- Prioritization
- Software co-development
- Model intercomparison and analysis
- Training
- Program review
- Organizational co-development

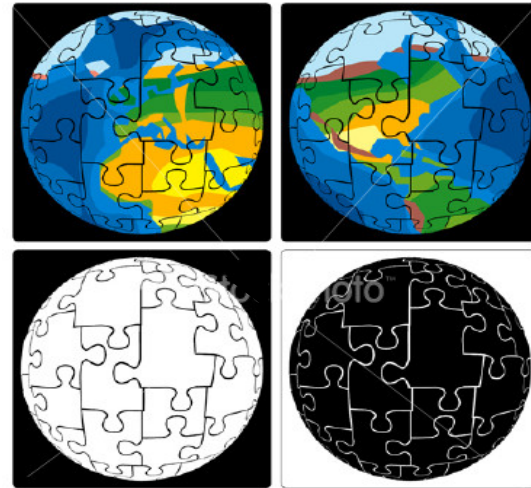
Assumptions?

- Enabling infrastructure
- Access to code and information
- Supportive communication and organizational structure

Enabling technologies for R2A

The Earth System Modeling Framework (ESMF) offers *standard interfaces* for **model components** and an architecture for model construction

Standard, community-developed component interfaces support a broad understanding of the requirements for integrating research components with operational components, and allow multiple groups to contribute components to coupled development and operational system.



Standard Component Interfaces

All ESMF components have the same three standard methods (these can have multiple phases)

- Initialize
- Run
- Finalize

Each standard method has the same simple interface:

```
call ESMF_GridCompRun (myComp, importState, exportState,  
clock, ...)
```

Where:

myComp points to the component

importState is a structure containing input fields

exportState is a structure containing output fields

clock contains timestepping information

Interfaces are [wrappers](#) and can often be introduced in a [non-intrusive way](#), i.e. ESMF is designed to coexist with native model infrastructure

Grid Remapping for Coupling

Uniquely fast, reliable, and general – interpolation weights computed in parallel in 3D space to support distributed development of **model components** and model coupling

Supported grids (include reduced Gaussian, MPAS, FIM, ORCA, tripole, cubed sphere, etc.)

- Logically rectangular grids, meshes, and observational data streams
- Global and regional grids, 2D and 3D grids

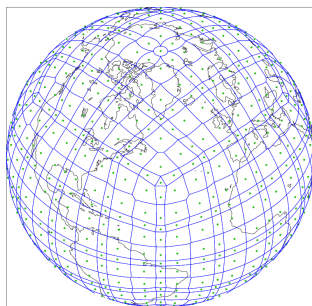
Supported interpolation methods:

- Nearest neighbor, higher order patch recovery (e.g. Khoei et al. 2007), bilinear and 1st order conservative methods

Options for straight or great circle lines, masking, and a variety of pole treatments

Flexible, fast grid remapping tools support data transformations that enable new components from the research community to be incorporated into operational systems.

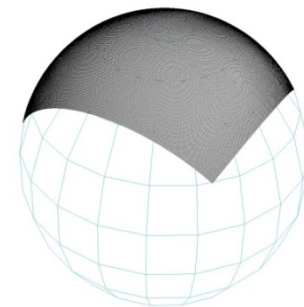
*Some
supported
grids ...*



HOMME Cubed Sphere Grid with
Pentagons
Courtesy Mark Taylor of Sandia




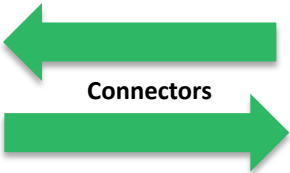
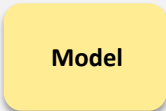
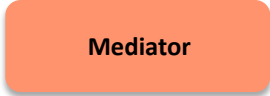
FIM Unstructured Grid

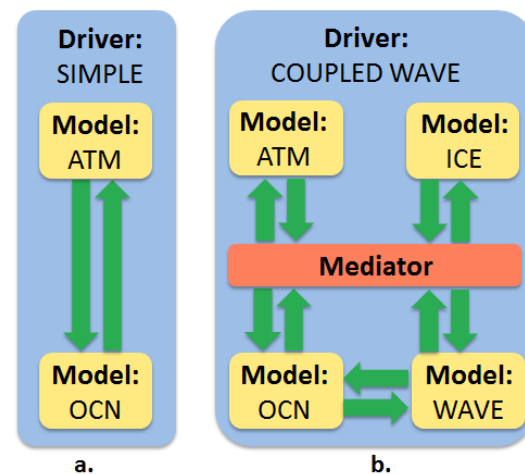


Regional Grid

The National Unified Operational Prediction Capability

- The National Unified Operational Prediction Capability (NUOPC) is a consortium of operational weather prediction centers and their research partners
- NUOPC developed the ESMF-based NUOPC Layer software to increase interoperability of **model components**
- NUOPC introduces a set of pre-fabricated model component templates for building coupled systems

NUOPC Generic Components	
	Harness that initializes components according to an <i>Initialization Phase Definition</i> , and drives their Run() methods according to a customizable run sequence.
	Implements field matching based on standard metadata and executes simple transforms (e.g. grid remapping, redistribution). It can be plugged into a generic Driver component to connect Models and/or Mediators.
	Wraps model code so it is suitable to be plugged into a generic Driver component.
	Wraps custom coupling code (flux calculations, averaging, etc.) so it is suitable to be plugged into a generic Driver component.

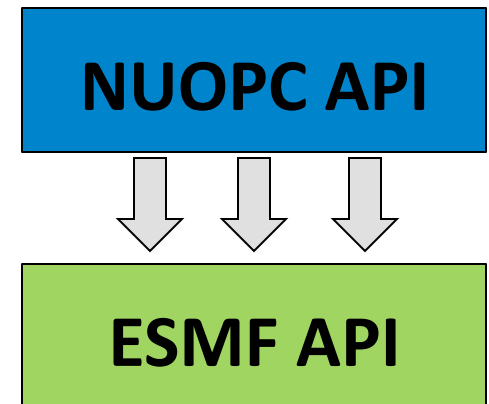


Simple driver (a) and schematic of COAMPS (b)

NUOPC Interoperability Layer

An interoperability layer on top of ESMF that adds:

- Definitions for **model component** interactions during Initialize, Run, Finalize
- Extensible, generic components that implement the component interactions above
- A field dictionary, based on Climate & Forecast (CF) **metadata** conventions, as the basis for a standard identification of fields between components
- Component Explorer and Compliance Checker tools that report component incompatibilities detected during run-time
- Static compliance checking and code generation via the Cupid Integrated Development Environment



Related Projects: ESPS

- The Earth System Prediction Suite (ESPS) is a collection of weather and climate modeling codes that use ESMF with the NUOPC conventions.
- Currently, **model components** in the ESPS can be of the following types:
coupled system, atmosphere, ocean, wave, sea ice

Target codes include:

- The Community Earth System Model (CESM)
- The NOAA Environmental Modeling System (NEMS) and Climate Forecast System version 3 (CFSv3)
- The MOM5 and HYCOM oceans
- The Navy Global Environmental Model (NavGEM)-HYCOM-CICE coupled system
- **The Navy Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS) and COAMPS Tropical Cyclone (COAMPS-TC)**
- NASA GEOS-5
- NASA ModelE

<https://www.earthsystemcog.org/projects/esps/>

ESPS Code Status

ESPS COUPLED MODELING SYSTEMS						
	NEMS and CFS	COAMPS	NavGEM	GEOS-5	ModelE	CESM
Model Driver	●	●	●	●	●	●
ATMOSPHERE MODELS						
GSM	●					
NMMB	●					
CAM						●
FIM	●					
GEOS-5 Atmosphere				●		
ModelE Atmosphere					●	
COAMPS Atmosphere		●				
NavGEM			●			
NEPTUNE			●			
OCEAN MODELS						
MOM5	●			●		
HYCOM	●		●		●	●
NCOM		●				
POP						●
POM	●					
SEA ICE MODELS						
CICE	●		●	●	●	●
KISS	●					
OCEAN WAVE MODELS						
WW3	●	●		●		●
SWAN		●				

LEGEND

- Components are NUOPC compliant and the technical correctness of data transfers in a coupled system has been validated.
- Components and coupled systems are partially NUOPC compliant.

The many community and federal models available with NUOPC interfaces allows operational centers to leverage and test a variety of components more easily.

From Theurich et al. 2015, in submission

Earth System Framework Description Language (ES-FDL)

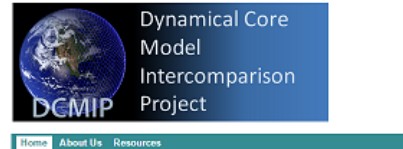
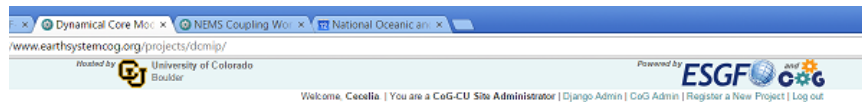
A **common language and associated tools** for describing the functional scope and characteristics of modeling infrastructure.

Uses of the ES-FDL:

- to describe and understand **infrastructure software**
- to discover modeling infrastructure with desired functionality
- to identify how different software packages compare in functionality
- to indicate how two (or more) infrastructure packages may connect or interact in order to support complex functions and cross-disciplinary interactions*

ES-FDL is a forward-looking initiative that aims to connect the ESMF infrastructure being used at NOAA with infrastructure from related disciplines used in the research and operational communities (e.g. hydrology, agriculture)

Model Intercomparison Project Support



DCMIP
Home
Edit Site Index

Visitors
List All News
List All Files

Members
Publish News
Add Page
Add File
Add Resource

Administrators
List Pending Users
List Current Users
List All Site Users
List ESMF Data Groups
Update Project
Tag Project
Delete Project

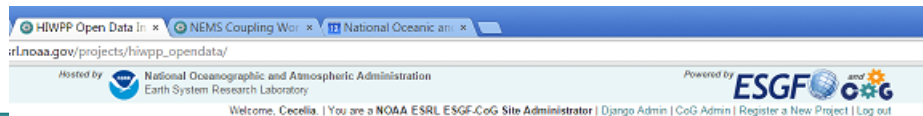
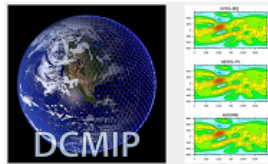
Site Administrators
Activate Projects
List System Users
Configure Peers

Dynamical Core Model Intercomparison Project

The Dynamical Core Model Intercomparison Project (DCMIP) atmospheric General Circulation Models (GCMs). The goal trade-offs of the many numerical and computational design and climate models. These options incorporate the choice computational grids and their grid staggering options, disk efficiency. In addition, the coupling strategy to physical parameter feedbacks are assessed. The assessments utilize a suite of test cases.

DCMIP is an international effort. We invite the international developers and all interested parties to join this virtual community. The Dynamical Core Model Intercomparison Project (DCMIP) will be served by this Community Governance (CoG) workshop and DCMIP-2012. The workshop hosts a VM functionality data sets hosted on the Earth System Grid, metadata, data and relevant links to resources, and some basic data analysis Access Server.

DCMIP-2012



HIWPP Open Data Initiative

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Open Data Initiative Info
Info & Instructions
NEIS Data
Real-Time Data Access
FAQ
Model Change Log
Stat. Post-Processing
Feedback
Edit Site Index

Visitors
List All News
List All Files

Members
Publish News
Add Page
Add File
Add Resource

Administrators
List Pending Users
List Current Users
List All Site Users
List ESMF Data Groups
Update Project
Tag Project
Delete Project

Site Administrators
Activate Projects
List System Users
Configure Peers

HIWPP Open Data Initiative

Welcome to the HIWPP Open Data Initiative

Important Announcements:
Please see the [Info & Instructions](#) page for announcements such as upcoming down times.

Real-Time Research

The HIWPP Open Data Initiative provides a mechanism for interaction between public, private, and academic sectors with our project as we develop and explore models that are relatively mature in their developmental life cycle.

Feedback for Model Development

We hope that you, the community, will help us to improve these models. Feedback on the model forecasts, the post-processed data, and the data delivery and visualization tools will be used to improve models and products.

Provide Feedback

Data Use

First and foremost, these are not the official products and forecasts of NOAA – those products and services are issued by the National Weather Service, and can be found at:

- Official Forecasts (NWS): <http://www.weather.gov>
- Official Model Products (NWS/NCEP): <http://imag.ncep.noaa.gov>

These model outputs and forecasts (other than GFS) are **EXPERIMENTAL**:

- They are provided without warranty of any kind and you use them at your own risk
 - The data and data streams are subject to change at any time
 - While the data will likely be stored long-term for R&D, in most cases, the real-time data streams are expected to terminate at the conclusion of this project
 - Data availability for HIWPP will not be maintained at as high a level as that for NWS operational models. Some outages will likely occur due to research computer outages, planned maintenance downtimes, or other reasons.
 - For GFS, this site will not have the same level of reliability as that of the official NCEP site. Please see the official NCEP site at <https://imag.ncep.noaa.gov> for the operational data.
- Finally, we ask that you credit the source of data in your usage.

You are at the NOAA ESRL ESMF-CoG node

My Profile | My Data Cart 0

Read News
Upcoming power outages
HIWPP data is served from NOAA facilities in ...

Browse Projects

This All My Tags

Parent projects (2)

HIWPP

HIWPP_Internal

Peer projects (7)

HIWPP_HurricaneNest

HIWPP_Hydrostatic

HIWPP_Management

HIWPP_NEIS

HIWPP_NWRE

HIWPP_NonHydrostatic

HIWPP_TestProgram

Child projects (1)

HIWPP_NEIS

Enter Tag

Save Tag Reset Go

Start typing, or use the Delete key to show all available tags

HIWPP_OpenData Tags: None

Model intercomparison and joint evaluation is a consequence of having more component choices.

The Earth System CoG environment support national and international projects like the Dynamical Core Intercomparison Project, HIWPP, and CMIP.

Overview of CoG

CoG is a collaboration environment and hub to connect projects in the Earth sciences.

It hosts and links into networks software development projects, **model intercomparison** projects (MIPS), events, and workshops.

It includes a configurable search to **datasets** on ANY Earth System Grid Federation (ESGF) data node.

It provides projects with a wiki and customizable navigation to wiki content.

It supports the **organization of complex networks of projects** and provides a consolidated look at this content across a project's network.

It provides services for Earth system model **metadata** collection and display (through ES-DOC tools)



Some of the 70+ projects currently hosted on CoG include:

- NOAA's High Impact Weather Prediction Project (HIWPP)
- Atmospheric Dynamical Core Model Intercomparison Project (DCMIP)
- Reanalysis Data for CMIP5 (Ana4MIPs)
- Observational Data for CMIP5 (Obs4MIPs)
- National Unified Operational Prediction Capability (NUOPC)
- National Climate Predictions and Projections Platform (NCP)
- Earth System Documentation (ES-DOC)
- Earth System Prediction Capability (ESPC)

Earth System Documentation (ES-DOC) is an international effort to develop tools to describe Earth system models in order to better understand and utilize model data. The tools are based on the [Common Information Model \(CIM\)](#) metadata standard.

CIM

A metadata standard used to describe Earth system models. This includes simulations, experiments, and computing resources used by those models. The CIM is now being leveraged by a variety of international model intercomparison projects.

Questionnaire

A customizable package to generate questionnaires that **CREATE** model documentation.

Viewer

A browser plugin to **DISPLAY** model documentation. It can be embedded directly into web pages but is also available via the Search or Comparator tools.

Comparator

A web-based tool to **COMPARE** CIM metadata records currently stored in the CIM archive. Comparison can be output as CSV files or HTML renderings.

Search

A publicly accessible portal to **SEARCH** on and **VIEW** model documentation.

SEARCH on and VIEW
CMIP5
model documentation

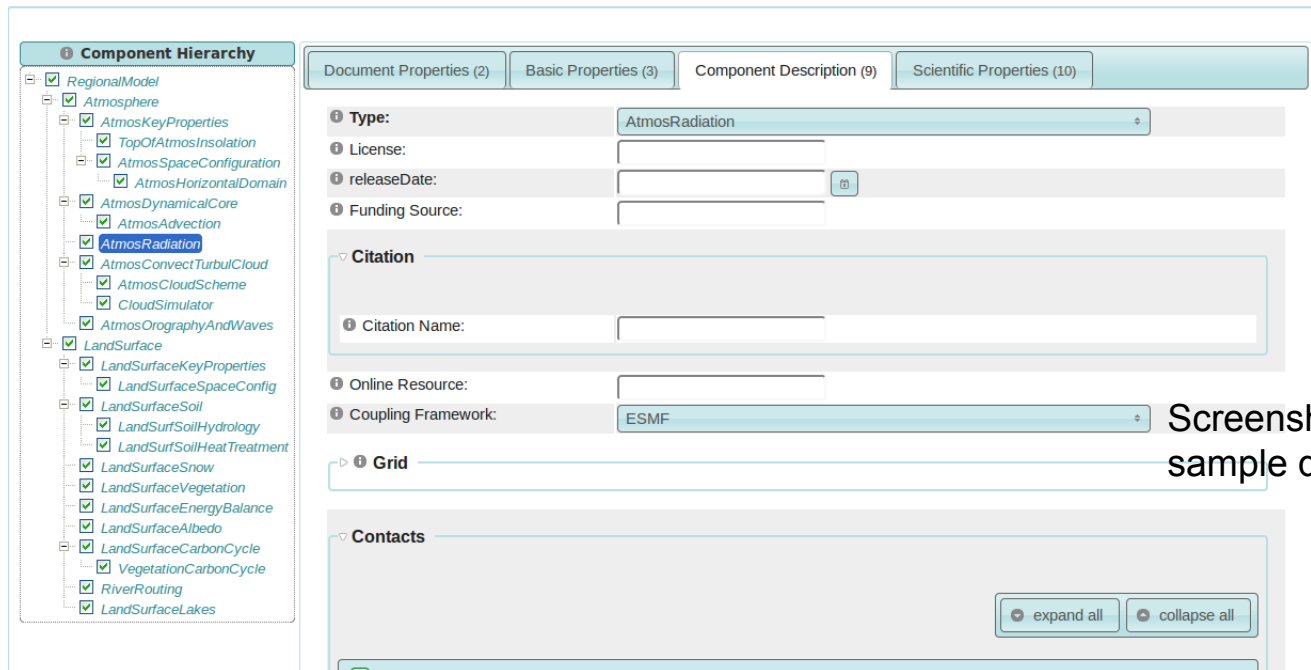
CMIP5 (the Coupled Modeling Intercomparison Project) is the international modeling effort underlying the IPCC assessments. Metadata describing the models used can be viewed at the link below.

<https://www.earthsystemcog.org/projects/es-doc-models/>

ES-DOC Questionnaire

Motivated by the need to collect model **metadata** for **model intercomparison** projects

Generates customizable ESM model questionnaires on the fly



The screenshot displays the ES-DOC Questionnaire interface. On the left, a 'Component Hierarchy' tree shows a selection of components under 'RegionalModel'. The 'AtmosRadiation' component is highlighted. The main form on the right is titled 'AtmosRadiation' and includes tabs for 'Document Properties (2)', 'Basic Properties (3)', 'Component Description (9)', and 'Scientific Properties (10)'. The 'Component Description' tab is active, showing fields for 'Type' (AtmosRadiation), 'License', 'releaseDate', 'Funding Source', 'Citation Name', 'Online Resource', and 'Coupling Framework' (ESMF). There are also sections for 'Grid' and 'Contacts'.

Screenshot of a sample questionnaire

Cupid Development Environment

Cupid is a development tool to make adoption of ESMF/NUOPC infrastructure *faster, easier, and more appealing* for both research and operational communities.

Goals:

- help developers **understand** how the NUOPC API is used in a specific application
- accelerate **creation** of new NUOPC components
- simplify **modification** of existing NUOPC applications
- provide a streamlined **training** environment by combining a diverse set of development tools into one application

Cupid is a Plugin for Eclipse

Cupid adds ESMF/NUOPC-specific features to the *Eclipse IDE*



Fortran source code editor

```

module ATM
!-----
! ATM Component.
!-----

use ESMF
use NUOPC
use NUOPC_Model, only: &
    model_routine_SS => routine_SetServices, &
    model_label_Advance => label_Advance

implicit none

private

public SetServices

!-----
contains
!-----
    
```

Project explorer

- AtmOcnMedProto 225 [http://svn.co
- AtmOcnPetList
- AtmOcnProto 225 [http://svn.code.s
- NUOPCCoupledAtmOcn
- NUOPCCoupledAtmOcnMed
 - atm.F90
 - esm.F90
 - esmApp.F90
 - med.F90
 - ocn.F90
 - atm.mod
 - atm.o
 - esm.mod
 - esm.o
 - esmApp
 - esmApp.o
 - Makefile
 - med.mod
 - med.o
 - ocn.mod
 - ocn.o
 - README
- nuopdef
- SingleModelProto 225 [http://svn.co
- SingleModelProtoF 225 [http://svn.co

NUOPC view

NUOPC Definition	Value
NUOPC Application	
name	(none)
NUOPC Model	OCN
NUOPC Model	ATM
Model Name	ATM
Generic Imports	
importsGenericSS	model_routine_SS
Set Services	SetServices
Initialization	
phase 0	
phase 1	InitializeP1
phase 2	InitializeP2
phase 3	
Set Clock (optional)	
phase 4	
phase 5	
Run	
Finalize	

Console for viewing output

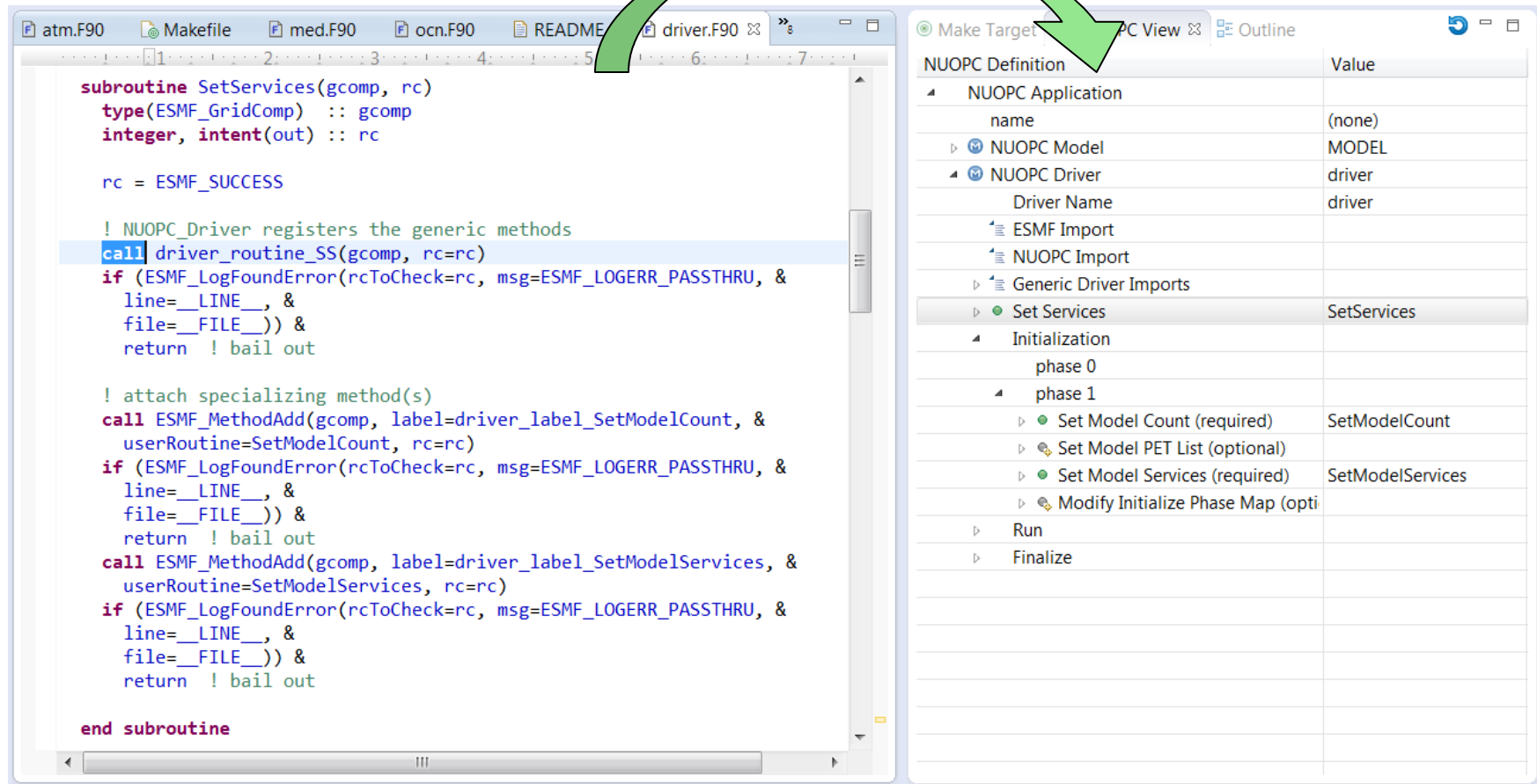
```

CDT Build Console [NUOPCCoupledAtmOcnMed]
07:43:00 **** Build of configuration Cupid_Configuration for project NUOPCCoupledAtmOcnMed ****
make esmApp
mpif90 -c -O -fPIC -m64 -mcmodel=small -pthread -ffree-line-length-none -fopenmp -I/home/sgadmin/esmf/DEFAULTINSTALLDIR/mod/mod0/Linux.
mpif90 -c -O -fPIC -m64 -mcmodel=small -pthread -ffree-line-length-none -fopenmp -I/home/sgadmin/esmf/DEFAULTINSTALLDIR/mod/mod0/Linux.
mpif90 -c -O -fPIC -m64 -mcmodel=small -pthread -ffree-line-length-none -fopenmp -I/home/sgadmin/esmf/DEFAULTINSTALLDIR/mod/mod0/Linux.
mpif90 -c -O -fPIC -m64 -mcmodel=small -pthread -ffree-line-length-none -fopenmp -I/home/sgadmin/esmf/DEFAULTINSTALLDIR/mod/mod0/Linux.
mpif90 -c -O -fPIC -m64 -mcmodel=small -pthread -ffree-line-length-none -fopenmp -I/home/sgadmin/esmf/DEFAULTINSTALLDIR/mod/mod0/Linux.
mpif90 -m64 -mcmodel=small -pthread -fopenmp -L/home/sgadmin/esmf/DEFAULTINSTALLDIR/lib/lib0/Linux.gfortran.64.openmpi.default -L/usr/l
> Shell Completed (exit code = 0)

07:43:15 Build Finished (took 14s.965ms)
    
```


Understand what's there:

Create an outline of an ESMF/NUOPC Application



The image shows a development environment with two panels. The left panel displays Fortran code for a subroutine `SetServices`. The right panel shows a hierarchical outline of the NUOPC application structure.

Fortran Code (Left Panel):

```

subroutine SetServices(gcomp, rc)
  type(ESMF_GridComp) :: gcomp
  integer, intent(out) :: rc

  rc = ESMF_SUCCESS

  ! NUOPC_Driver registers the generic methods
  call driver_routine_SS(gcomp, rc=rc)
  if (ESMF_LogFoundError(rcToCheck=rc, msg=ESMF_LOGERR_PASSTHRU, &
    line=__LINE__, &
    file=__FILE__)) &
    return ! bail out

  ! attach specializing method(s)
  call ESMF_MethodAdd(gcomp, label=driver_label_SetModelCount, &
    userRoutine=SetModelCount, rc=rc)
  if (ESMF_LogFoundError(rcToCheck=rc, msg=ESMF_LOGERR_PASSTHRU, &
    line=__LINE__, &
    file=__FILE__)) &
    return ! bail out
  call ESMF_MethodAdd(gcomp, label=driver_label_SetModelServices, &
    userRoutine=SetModelServices, rc=rc)
  if (ESMF_LogFoundError(rcToCheck=rc, msg=ESMF_LOGERR_PASSTHRU, &
    line=__LINE__, &
    file=__FILE__)) &
    return ! bail out

end subroutine
  
```

NUOPC Application Outline (Right Panel):

NUOPC Definition	Value
NUOPC Application	
name	(none)
NUOPC Model	MODEL
NUOPC Driver	driver
Driver Name	driver
ESMF Import	
NUOPC Import	
Generic Driver Imports	
Set Services	SetServices
Initialization	
phase 0	
phase 1	
Set Model Count (required)	SetModelCount
Set Model PET List (optional)	
Set Model Services (required)	SetModelServices
Modify Initialize Phase Map (optional)	
Run	
Finalize	

Check for issues: Static Compliance Checking

Make Target *NUOPC View Outline	
NUOPC Definition	Value
NUOPC Application	
name	(none)
NUOPC Model	MODEL
NUOPC Driver	driver
Driver Name	driver
ESMF Import	
NUOPC Import	
Generic Driver Imports	
Set Services	SetServices
Initialization	
phase 0	
phase 1	
Set Model Count (required)	
Set Model PET List (optional)	
Set Model Services (required)	SetModelServices
Modify Initialize Phase Map (optional)	
Run	
phase 1	
Finalize	

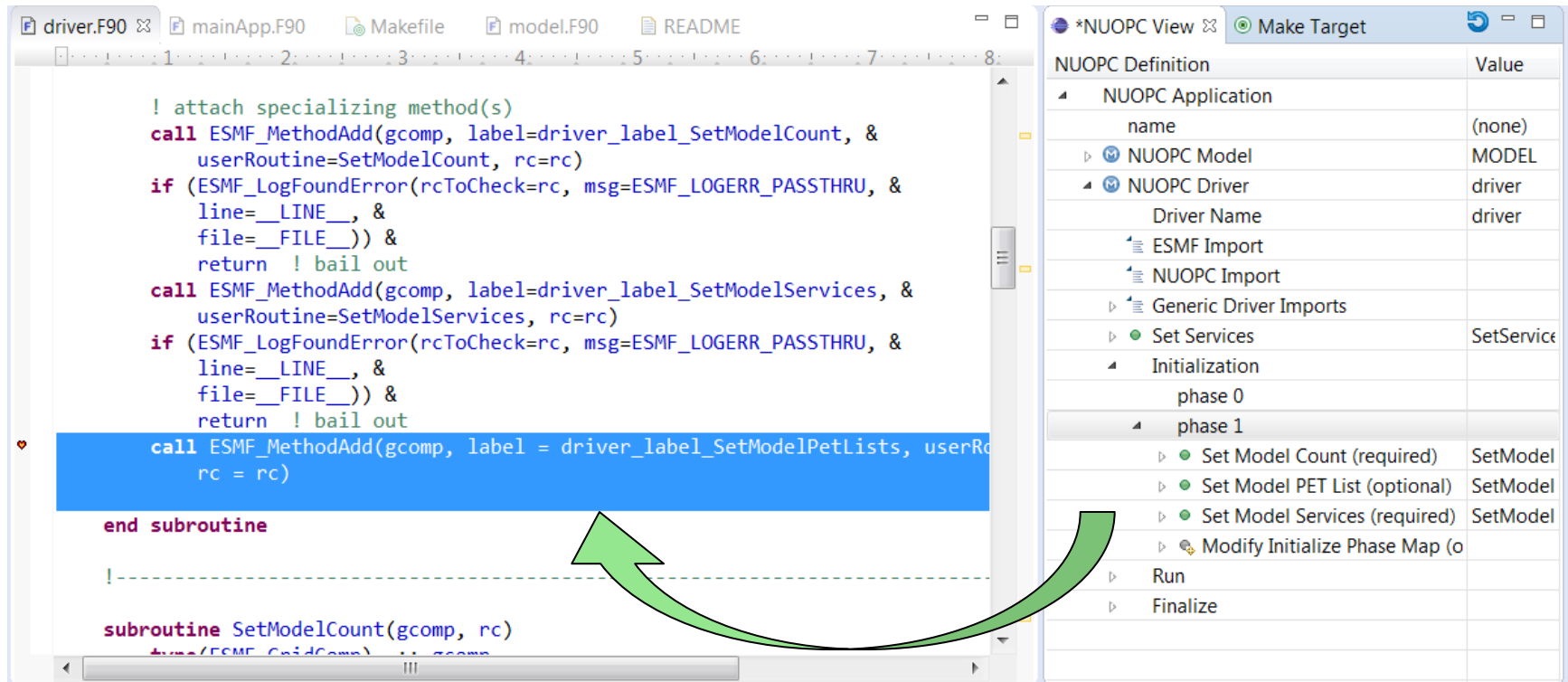
NUOPC provided.

- If the incoming clock is valid, set the internal stop time to one time step interval on the incoming clock.
- Time stepping loop, from current time to stop time, incrementing by time step.
- For each time step iteration, the Model and Connector components Run() methods are being called according to the run sequence.

NUOPC View

- compact outline of NUOPC component source code
- linked with source code editor
- contextual reference documentation
- compliance issues shown in red

Write compliant code: In-place Code Generation



The screenshot shows the ESMF IDE with the following components:

- File Explorer:** driver.F90, mainApp.F90, Makefile, model.F90, README
- Code Editor:**

```

! attach specializing method(s)
call ESMF_MethodAdd(gcomp, label=driver_label_SetModelCount, &
  userRoutine=SetModelCount, rc=rc)
if (ESMF_LogFoundError(rcToCheck=rc, msg=ESMF_LOGERR_PASSTHRU, &
  line=__LINE__, &
  file=__FILE__)) &
  return ! bail out
call ESMF_MethodAdd(gcomp, label=driver_label_SetModelServices, &
  userRoutine=SetModelServices, rc=rc)
if (ESMF_LogFoundError(rcToCheck=rc, msg=ESMF_LOGERR_PASSTHRU, &
  line=__LINE__, &
  file=__FILE__)) &
  return ! bail out
call ESMF_MethodAdd(gcomp, label = driver_label_SetModelPetLists, userR
rc = rc)

end subroutine

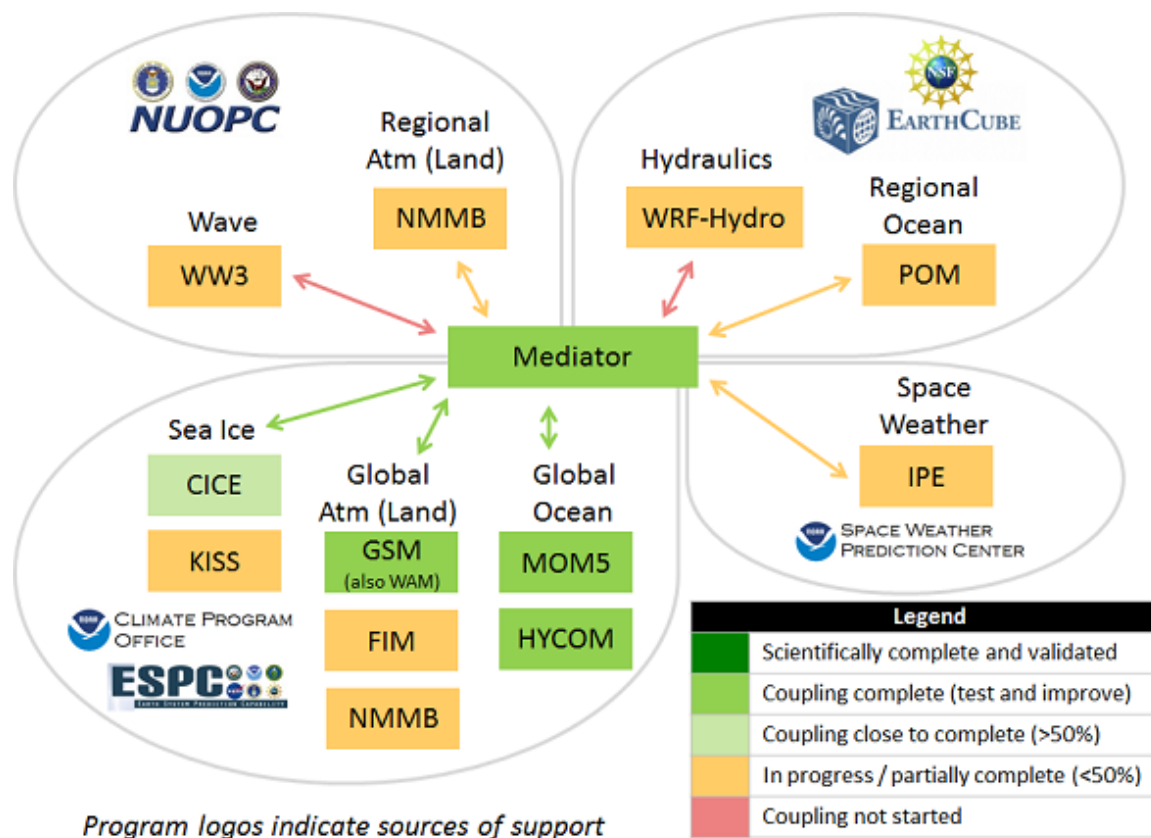
!-----
subroutine SetModelCount(gcomp, rc)
  type(ESMF_GridComp) :: gcomp

```
- NUOPC View Table:**

NUOPC Definition	Value
NUOPC Application	
name	(none)
NUOPC Model	MODEL
NUOPC Driver	driver
Driver Name	driver
ESMF Import	
NUOPC Import	
Generic Driver Imports	
Set Services	SetService
Initialization	
phase 0	
phase 1	
Set Model Count (required)	SetModel
Set Model PET List (optional)	SetModel
Set Model Services (required)	SetModel
Modify Initialize Phase Map (o	
Run	
Finalize	

A green arrow points from the 'Set Model Count (required)' entry in the NUOPC View table to the corresponding line in the code editor.

R2A component and collaboration infrastructure used throughout NEMS



Coupled NEMS, incl. coupler description and schematic:
<http://cog-esgf.esrl.noaa.gov/projects/couplednews/>

NESII Collaborators and Customers

- NOAA ESRL GSD/PSD, GFDL, NCDC, PMEL, NCEP Environmental Modeling Center
- NASA JPL, Goddard Space Flight Center, GISS
- DOE PCMDI, Argonne National Laboratory, ORNL, Sandia
- DoD NRL Stennis and Monterey, Naval Oceanography, Army ERDC, Air Force Weather Agency
- NCAR Community Earth System Model, WRF, MPAS, HAO, Unidata
- University of Michigan, Purdue University, University of South Carolina, University of Colorado, Colorado State University, Georgia Institute of Technology
- GO-ESSP, CUAHSI, CSDMS, OpenMI, OGC, CCA, METAFOR
- Delft Hydraulics, British Atmospheric Data Center, CERFACS, IPSL, Univ. Reading, UK Met Office, DKRZ, MPI
- Many more ...